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GRAVITY-ACTUATED SUBMARINE ANTENNA

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT DAVID F. RIVERA, employee of the United States Government, citizen of the United States of America, and resident of Westerly, County of Washington, State of Rhode Island has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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3 **GRAVITY-ACTUATED SUBMARINE ANTENNA**

4
5 **STATEMENT OF GOVERNMENT INTEREST**

6 The invention described herein may be manufactured and used
7 by or for the Government of the United States of America for
8 governmental purposes without the payment of any royalties
9 thereon or therefor.

10
11 **BACKGROUND OF THE INVENTION**

12 **(1) Field of the Invention**

13 The present invention relates to antennas and more
14 particularly to radiators for low profile, towed antennas.

15 **(2) Description of the Prior Art**

16 Present submarine communications with battlegroups or shore
17 sites utilize surface antennas for a variety of requirements
18 including SATCOM, LOS, etc. The use of surface antennas
19 typically interferes with the covert operation of the submarine.
20 For example, data exchange or the receipt of commands is
21 accomplished by using antennas within a mast, which must be
22 extended whenever transmission or reception is required. For
23 communications in coastal or littoral areas, raising a mast
24 renders the submarine vulnerable to visual or radar detection.

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1 To mitigate such detection, buoyant cable antennas (BCA) are
2 often used. However, current BCAs cannot be used effectively
3 for transmission, due to their extremely low radiation
4 efficiency.

5 Furthermore, antennas towed on the ocean surface are
6 subjected to dynamic forces that act to cause the antenna to
7 pitch, yaw and sometimes roll under varying sea states. These
8 antenna movements can easily result in transmission and
9 reception interruption, especially so with the use of
10 directional antennas. As a result, the towing submarine must
11 operate in a station keeping status or must constantly adjust
12 course headings in order to obtain optimal antenna performance.

13 In Rivera et al. (U.S. Patent No. 6,127,983), there is
14 disclosed a wideband antenna capable of transmission and
15 reception while the antenna is towed horizontally in the ocean
16 behind the submarine or vessel. Specifically, the antenna of
17 the cited reference is formed as a metal cylinder having a
18 longitudinal slot with the longitudinal slot open at one end and
19 closed at the other end. The cylindrical shape in a towing
20 container provides a strong righting moment to the antenna with
21 the result of efficient broadband coverage under varying sea
22 states.

23 Also, by setting the terminations of the antenna, that is,
24 the open end, the closed end, and the feedpoint (along with the

1 antenna diameter and thickness, and slot length and width) an
2 antenna having a good impedance match over a wide frequency band
3 is produced.

4 As disclosed, the above antenna is clearly suitable for
5 wideband transmission when being towed in the ocean; however, an
6 alternative antenna is desirable to produce an increased
7 effectiveness during operation and an increased range of use
8 when compared to the above antenna as well as for other known
9 buoyant antennas.

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SUMMARY OF THE INVENTION

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Accordingly, it is a general purpose and primary object of
the present invention to provide an antenna that can transmit a
directionalized radiation pattern with minimal interruption when
operating in varying sea states.

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It is a further object of the present invention to provide
an antenna in which the antenna construction is simple and
economical.

19

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It is a still further object of the present invention to
provide an antenna with an increased antenna gain.

21

22

23

It is a still further object of the present invention to
provide an antenna that operates efficiently over a wide band of
frequencies.

1 It is a still further object of the present invention to
2 provide an antenna in which the operation of the antenna is roll
3 stable.

4 It is a still further object of the present invention to
5 provide an antenna that emits a symmetrical radiation pattern in
6 the fore/aft and athwart directions.

7 To attain the objects described there is provided a
8 gravity-actuated antenna suitable for towing horizontally on the
9 ocean surface in which the antenna includes a switching system
10 that actuates the antenna when facing "up" toward the sky or
11 ocean surface. The antenna comprises a cylindrical feed tube
12 with three radially extending fins and disk plates secured to
13 ends of the feed tube and the fins. A plurality of the curved
14 plates spaced apart an extending plane of the fins and
15 projecting from an end plate partially encompass and subtend to
16 the length of the feed tube with each curved plate connected to
17 the feed tube by the protecting structure of a gravity-actuated
18 electrical switch.

19 The fins of the antenna are spaced evenly around the
20 circumference of the feed tube. Each fin is sized to form a
21 longitudinal radiation boundary of a resonant cavity and the end
22 plates are sized to form an athwart radiation boundary of the
23 resonant cavity with the exterior of the feed tube forming the
24 base of the resonant cavity. The boundaried resonant cavity is

1 shallow enough that the cavity is not shadowed by the radial
2 fins and the end plates. Without a shadow condition restricting
3 a wavelength generated in the resonant cavity during antenna
4 actuation, a resultant symmetrical radiation pattern can be
5 transmitted in conjunction with the actuation of a specified
6 curved plate.

7 The feed tube encompasses a first transmission line from a
8 feedpoint terminus at one end plate to a cylindrical feed hub
9 within the feed tube. The transmission line is capable of
10 conducting radio-frequency energy from the terminus to the hub
11 and onto an individual electrical switch when the switch is
12 gravity-actuated as a result of a righting motion of the curved
13 plates. Energy from the hub via the switch and onto a specified
14 curved plate and further onto the resonant cavity results in a
15 current distribution across the curved plate and the resonant
16 cavity such that a difference in phase between both results in
17 the radiation pattern beamed from the antenna. Based on the
18 sizing of the components of the antenna, the resultant radiation
19 pattern can be transmitted from a fore and aft direction in
20 relation to the antenna as well as at an athwart direction and
21 at a direction perpendicular to the axis of the feed tube.

22 By decreasing the diameter of the transmission line from
23 the feedpoint terminus to the hub, the transmission line
24 performs an impedance transformation over its length. The

1 impedance transformation of the transmission line among varying
2 diameters presents a variable load (Ω) at the feedpoint terminus
3 thereby allowing the antenna to emit over a range of
4 frequencies.

5 A second transmission line with a diameter equal to the
6 smallest diameter of the first transmission line and
7 electrically connectable to the hub, continues from the hub onto
8 a second terminus at the other end plate. The second
9 transmission line and the second terminus behave as a reactive
10 impedance to match the impedance at the connection of a pin of
11 the switch and the hub. By matching the impedance, an optimum
12 amount of radio-frequency energy can be transferred onto the
13 actuated switch and curved plate with a result in increased gain
14 of the antenna.

15 The above and other features of the invention, including
16 various and novel details of construction and combinations of
17 parts will now be more particularly described with reference to
18 the accompanying drawings and pointed out in the claims. It
19 will be understood that the particular devices embodying the
20 invention are shown by way of illustration only and not as the
21 limitations of the invention. The principles and features of
22 this invention may be employed in various and numerous
23 embodiments without departing from the scope of the invention.

1 **BRIEF DESCRIPTION OF THE DRAWINGS**

2 A more complete understanding of the invention and many of
3 the attendant advantages thereto will be readily appreciated as
4 the same becomes better understood by reference to the following
5 detailed description when considered in conjunction with the
6 accompanying drawings wherein:

7 FIG. 1 is a perspective view of the gravity-actuated
8 antenna of the present invention showing the physical
9 configuration of the antenna;

10 FIG. 2 is an alternate perspective view of the antenna of
11 the present invention with the view taken from reference line 2-
12 2 of FIG. 1;

13 FIG. 3 is a cross-sectional view of the antenna of the
14 present invention with a curved plate of the antenna removed for
15 a clarified view of the electrical transmission structure of the
16 antenna with the view taken from reference line 3-3 of FIG. 2;

17 FIG. 4 is an end view of the antenna of the present
18 invention with a curved plate, the feed tube and the radial fins
19 of the antenna removed and with the view inverted for a
20 clarified view of the electrical switch configuration of the
21 antenna with the view taken from reference line 4-4 of FIG. 2;

22 FIG. 5 is a cross-sectional view of the conductive
23 relationship of the feed hub to the electrical switches of the

1 antenna of the present invention with the view taken from
2 reference line 5-5 of FIG. 4;

3 FIG. 6 is a three-dimensional view of a radiation pattern
4 formed by the antenna of the present invention;

5 FIG. 7 is a cross-sectional view of a first variant of the
6 electrical switch of the antenna of the present invention; and

7 FIG. 8 is a cross-sectional view of a second variant of the
8 electrical switch of the antenna of the present invention.

9

10 DESCRIPTION OF THE PREFERRED EMBODIMENT

11 Referring now to the drawings wherein like numerals refer
12 to like elements throughout the several views, one sees that
13 FIG. 1 depicts the gravity-actuated submarine antenna 10 of the
14 present invention. The antenna 10 is preferably cast with a
15 rigid thickness from aluminum with brass electrically conductive
16 components attached. Other commonly acquired materials or
17 methods known to those skilled in the art may be used in forming
18 the antenna 10. Such a variant in antenna formation would be
19 molding the antenna 10 from plastic and plating the antenna with
20 a conductive material. Another non-exclusive variant in antenna
21 formation would be molding the antenna 10 from conductive
22 material.

23 The simplified structure of the antenna 10 generally
24 comprises a cylindrical feed tube 12 with radially extending

1 fins 14 and disk plates 16, 18 secured to ends of the feed tube
2 12 and the fins 14. A plurality of curved metal plates 20
3 spaced apart from the fins 14 and projecting from the end plate
4 16 partially encompass the length of the feed tube 12 with each
5 curved plate 20 connected to the feed tube 12 by a flange 21 and
6 the protective structure of an electrical switch 22.

7 Each curved plate 20 of the antenna 10 projects at a
8 distance (A) of $\lambda/3$ from the end plate 16, wherein λ is the
9 wavelength corresponding to the center design frequency. The
10 center design frequency is the geometric mean frequency between
11 the frequencies provided to the antenna 10. Each curved plate
12 20 subtends to the feed tube 12 at an angle in the range of 45°
13 to 90° , with the high end of the range preferred for broadened
14 antenna bandwidth.

15 The radial fins 14 of the antenna 10 are spaced at 120°
16 from each other around the circumference of the feed tube 12.
17 Each radial fin 14 is sized to form a longitudinal radiation
18 boundary of a resonant cavity 23 (a volume shown) with the
19 dimensions of each radial fin 14 at $\lambda/22$ in width (B) and $2 \times$
20 $\lambda/5$ in length (C). The end plates 16, 18 are sized to form an
21 athwart radiation boundary of the resonant cavity 23 with the
22 diameter of each of the end plates 16, 18 sized to be $\lambda/8$. An
23 exterior of the feed tube 12 forms the base of the resonant
24 cavity 23.

1 The bounded resonant cavity 23 is shallow enough that
2 the cavity is not shadowed by the radial fins 14 nor the end
3 plates 16, 18. Without a shadow condition restricting a
4 wavelength generated in the resonant cavity 23 during actuation
5 of the antenna 10, a resultant symmetrical radiation pattern 24
6 can be transmitted in conjunction with the actuation of a
7 specified curved plate 20. As discussed below for FIG. 6, the
8 resultant radiation pattern 24 can be transmitted from a fore
9 and aft direction as well as at an athwart direction and at a
10 direction perpendicular to the axis of the feed tube 12.

11 The end plate 16 further includes a stub terminus 25 to the
12 feed tube 12 through a central portion of the end plate 16 and
13 as shown in FIG. 2, the end plate 18 includes a feedpoint
14 terminus 26 to the feed tube 12 through a central portion of the
15 end plate 18. The terminus 26 and the terminus 25 are
16 respectfully at the ends of the coaxial transmission lines 30
17 and 32 shown in FIG. 3.

18 As shown in the cross-sectional view of FIG. 3, the feed
19 tube 12 encompasses and protects the transmission line 30 with
20 the transmission line 30 continuing from the terminus 26 to a
21 cylindrical feed hub 34. The diameter of the feed tube 12 is
22 sized to contain the transmission lines 30 and 32 without
23 impacting the impedance seen at the hub 34 such that the
24 diameter of the feed tube is slightly larger than the hub 34.

1 The transmission line 30 is capable of conducting radio-
2 frequency energy from the terminus 26 to the hub 34 and onto an
3 individual electrical switch 22 when the switch 22 is actuated
4 by the electrical connection of the hub 34 to the switch 22 (the
5 connection of conducting wire 36 within the switch 22 is shown
6 in FIG. 5, FIG. 7 and FIG. 8). Energy from the switch 22 and
7 onto a specified curved plate 20 and outward to the resonant
8 cavity 23 results in the radiation pattern 24 of the antenna 10.

9 By decreasing the diameter of the transmission line 30 in a
10 stepwise or tapered manner, the transmission line 30 performs an
11 impedance transformation over its length. The impedance
12 transformation of the transmission line 30 among varying
13 diameters presents a variable load (Ω) at the terminus 26
14 thereby allowing the antenna 10 to emit over a range of
15 frequencies. Because the switch 22 and the curved plate 20
16 would each have a unique impedance based on their structure and
17 size, the degree of tapering of the transmission line 30 (or
18 lack thereof) also depends on the dimensions of the switch 22
19 and the curved plate 20.

20 As further shown in FIG. 3, the second transmission line 32
21 has a diameter equal to the smallest diameter of the
22 transmission line 30. The second transmission line 32 is
23 electrically connectable to the hub 34 and continues from the
24 hub 34 onto the terminus 25 such that the transmission line 32

1 and the terminus 25 behave as a short-circuit electrically in
2 parallel with the connection of a pin 38 of the switch 22 and
3 the hub 34. The length and the diameter of the transmission
4 line 32 determines the amount of reactive impedance of the
5 transmission 32 to match the impedance at the connection of the
6 pin 38 and the hub 34. By matching the impedance, an optimum
7 and undistorted amount of radio-frequency energy can be
8 transferred onto the actuated switch 22 and curved plate 20 with
9 a result in increased gain of the antenna 10.

10 As shown in FIG. 4, the antenna 10 preferably includes
11 three switches 22 positioned equidistant along the circumference
12 of the feed tube 12 with the attached curved plates 20 also
13 positioned equidistant. Since three curved plates 20 are
14 attached, the chord width (D) of the curved plate 20 can be
15 maximized to enhance a angular range of a righting or "facing
16 up" action that mechanically actuates the switch 22. By
17 maintaining the righting action of the actuated switch 22 over a
18 widened range, the operation of the antenna 10 thereby becomes
19 roll-stable during towing. Additionally, the maximum chord
20 width (D) of the curved plate 20 permits a greater bandwidth to
21 be emitted from the antenna 10. Because the attachment point of
22 the switch 22 to the curved plate 20 also affects the impedance
23 bandwidth of the antenna 10, the preferred attachment point 42
24 is $\lambda/6$ from the open edge 44.

1 A cross-sectional view of the electrical switch 22 of the
2 antenna 10 used for the actuation described below is shown in
3 FIG. 5; however, other suitable variations of the switch 22 are
4 described for FIG. 7 and FIG. 8. As stated above, the
5 dimensions of the switch 22, specifically its supporting
6 structure, can affect the impedance seen at the terminus 26. As
7 such, the desired diameter (E) of the switch 22 is $\lambda/45$ and the
8 desired height (F) of the switch 22 is $\lambda/22$. The conical taper
9 50 of the switch 22 preferably has an angle of 45° and occupies
10 25% of the switch height(F). While the dimensions of the
11 supporting structure of the switch 22 are preferred for a center
12 design frequency over which the antenna 10 maintains a good
13 impedance match, other supporting structures for the switch 22
14 such as a cylinder without a taper may be used with compensating
15 changes in the diameter (E) and the height(F).

16 In the operation of the antenna 10, the feedpoint terminus
17 26 of the transmission line 30 is connected to a energized feed
18 source (not shown) at a portion of the UHF spectrum from 240-
19 270 MHz. The transmission line 30 allows the radio-frequency
20 energy to be conducted via the hub 34 and onto an electrical
21 switch 22. The conductive function of the switch 22 is actuated
22 by gravity whenever the attached curved plate 20 is righted or
23 faces "upwards" as a result of wave action buoying the curved
24 plate 20. The attached curved plate 20 is typically able to be

1 righted at an angle greater than 17° relative to a horizontal
2 plane.

3 When the curved plate 20 is righted and the switch 22
4 inclines, a metal sphere 60 rolls to contact the conducting wire
5 36, conductive to the structure of the switch 22, with a wire 64
6 in contact with the pin 38. Energy from the hub 34 via the pin
7 38 continues to the curved plate 20. The energy to the curved
8 plate 20 results in a sinusoidal current distribution flowing
9 along and across a surface 66 of the curved plate 20. The
10 direction and intensity of the current distribution varies with
11 the frequency of the antenna 10.

12 When energized, the switch 22 also emits a sinusoidal wave
13 that sets up a current distribution on a surface 67, 68 of the
14 fins 14 and a surface 69 of the feed tube 12 in the resonant
15 cavity 23. The differences in phase from the various radiating
16 surfaces 66, 67, 68 and 69 contributes to the generally
17 hemispherical radiation or beam pattern 24, shown in FIG. 6.

18 In FIG. 6, the radiation pattern 24 is depicted as a
19 mathematical surface known as a horn cyclide (a variant of a
20 toroid) with a null 72 from the center the horn cyclide to the
21 lower point 73 of a surface 74. The horn-cyclide shaped
22 radiation pattern 24 is advantageous because when the antenna 10
23 is placed on the ocean surface, the radiation pattern 24 in the
24 air space above the ocean surface (shown by the area 76 above

1 the plane defined by the "x" and "y" coordinates) has a minimal
2 null area. As such, the radiation pattern 24 in the air space
3 permits full directionalized transmission allowing the towing
4 submarine to communicate when is the antenna 10 is subject to
5 conditions of pitch, yaw, and varying degrees of roll since the
6 antenna 10 will be righted to the plane defined by the "x" and
7 "y" coordinates and coincident to the ocean surface.

8 Since the emitting area of the radiation pattern 24 is
9 symmetrical, problems associated with asymmetrical radiation
10 patterns are avoided. The symmetrical radiation pattern 24 of
11 the antenna 10 allows the submarine or ship to operate the
12 antenna for optimal antenna performance without station keeping
13 or adjusting course headings.

14 An additional feature of the present invention is that the
15 structural ratio (identified by the wavelength dimensioning
16 above) of the various components of the antenna 10 allows the
17 radiation pattern 24 to remain symmetrical while maintaining the
18 compactness of the antenna 10. The compactness of the antenna
19 10 is naturally advantageous for many reasons including
20 detection minimalization and reduced drag. In defining the
21 compactness feature, the outer physical boundary of the antenna
22 10 is based on the size and placement of the end plates 16, 18
23 and the curved plates 20. For example, each curved plate 20 of
24 the antenna 10 projects at a distance (A) of $\lambda/3$ from the end

1 plate 16 with the diameter of the end plates 16, 18 sized to be
2 $\lambda/8$, therefore any remaining structure of the antenna 10 would
3 be within a circumferential boundary created by the above
4 dimensions. Also, the radial fins 14 of the antenna 10 are 2
5 times $\lambda/5$ in length (C) therefore any remaining structure of the
6 antenna 10 would be within a longitudinal boundary created by
7 the dimension of the radial fins 14.

8 While the metal sphere 60 shown in FIG. 5 is used in the
9 actuation of the switch 22 described above, other variations of
10 electrical contact within the switch 22 may be used. In a first
11 variant of the switch 22 shown in FIG. 7, the sphere 60 of the
12 switch 22 is substituted with a metal plunger 80. The use of
13 the plunger 80 may be preferred in some circumstances since the
14 shape as well as the size of the plunger 80 can affect the angle
15 of gravity-actuation.

16 In a second variation of the switch 22 shown in FIG. 8, the
17 plunger 80 or sphere 60 is substituted with a gravity-actuated
18 magnet 90. When the curved plate 20 is righted and the switch
19 22 inclines, the magnet 90 slides to close the normally open
20 contacts of the reed switch 96. This allows the reed switch 96
21 to be conductive to the structure of the switch 22 by the
22 conducting wires 38 and 64. The magnetic material for the switch
23 22 must have a substantial mass to perform a switch but the
24 material also must have a stable magnetic field. In order not

1 to affect the magnetic field or impedance properties of the
2 antenna 10, the switch 22 may be lined with magnetic shielding
3 foil material 98.

4 Thus by the present invention its objects and advantages
5 are realized and although preferred embodiments have been
6 disclosed and described in detail herein, its scope should be
7 determined by that of the appended claims.

3 **GRAVITY-ACTUATED SUBMARINE ANTENNA**

5 **ABSTRACT OF THE DISCLOSURE**

6 An antenna including a feed tube with radial fins and
7 circular plates at the ends of the tube and fins thereby forming
8 a boundary for a plurality of resonant cavities. Curved plates,
9 connected to the tube by switches of a switching system,
10 partially encompass and subtend to the length of the tube.
11 Interior to the tube, a transmission line from an end plate
12 terminus conducts radio-frequency energy from the terminus to a
13 hub and onto a switch of the switching system in which the
14 switch is mechanically reactive to and actuated by a righting
15 action of the curved plates when the curved plates encounter a
16 sea state. When actuated, energy from the switch distributes to
17 a proximate resonant cavity and curved plate to form a radiation
18 pattern based on the difference in phase of the resonant cavity
19 and curved plate.

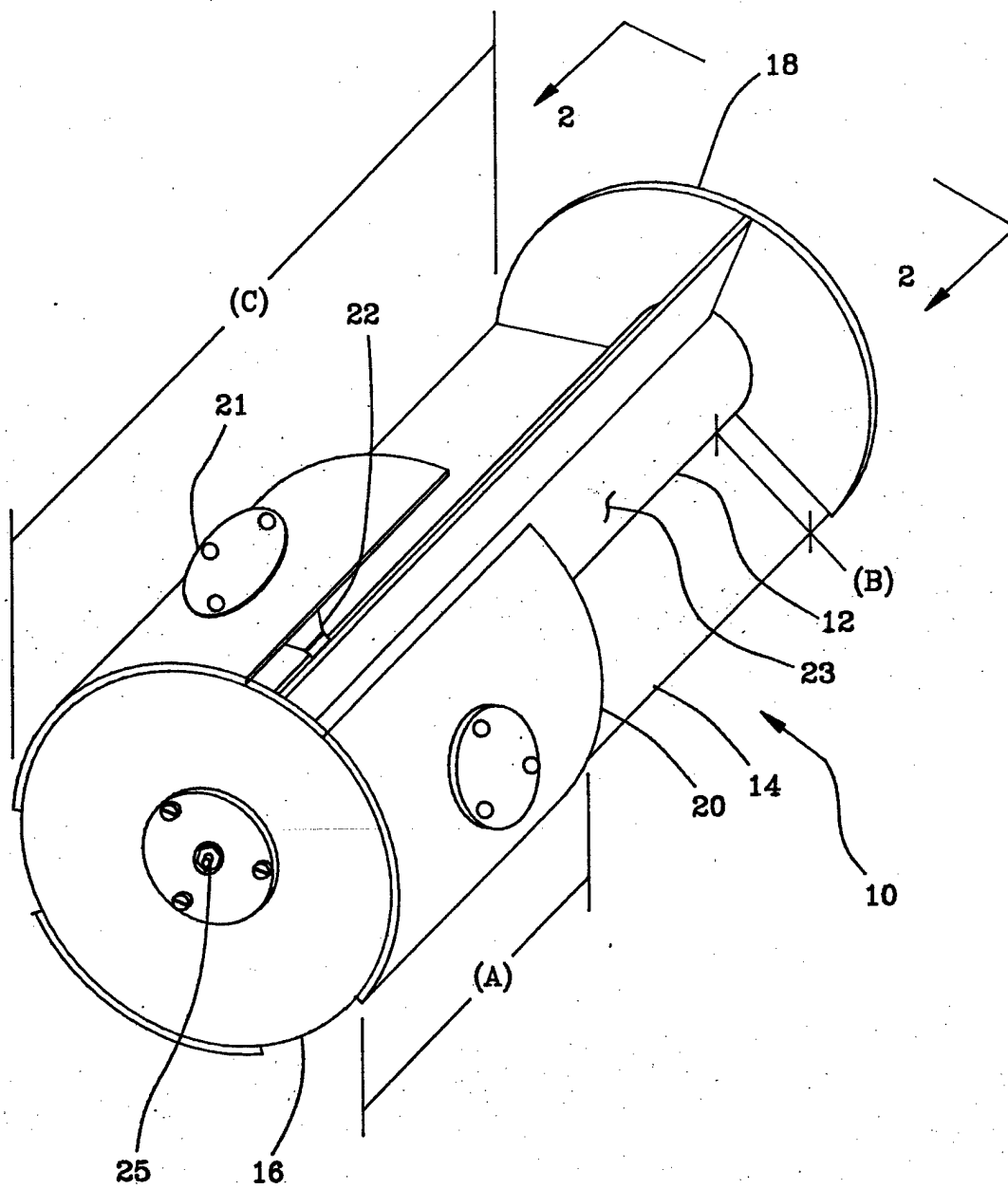


FIG. 1

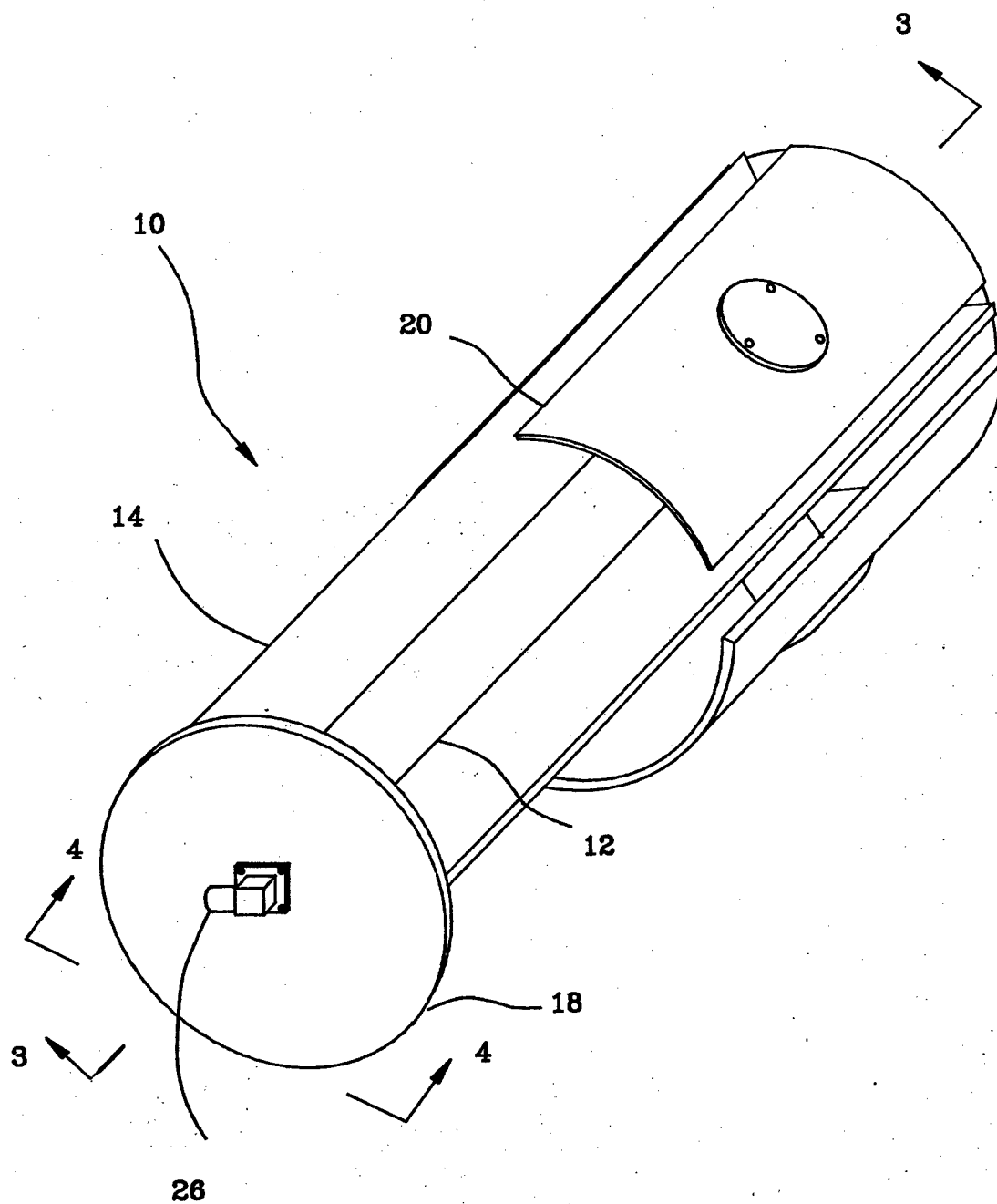


FIG. 2

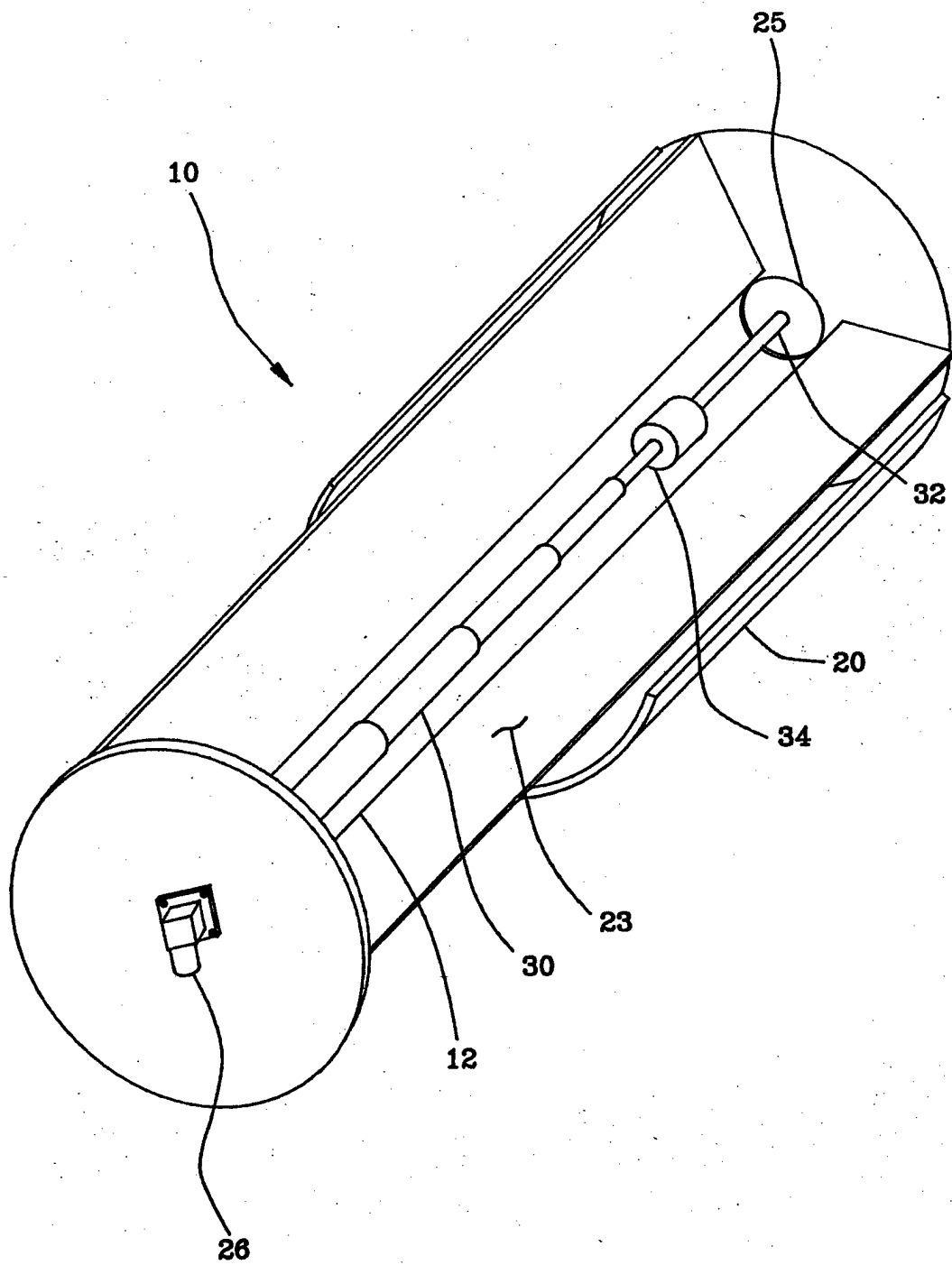


FIG. 3

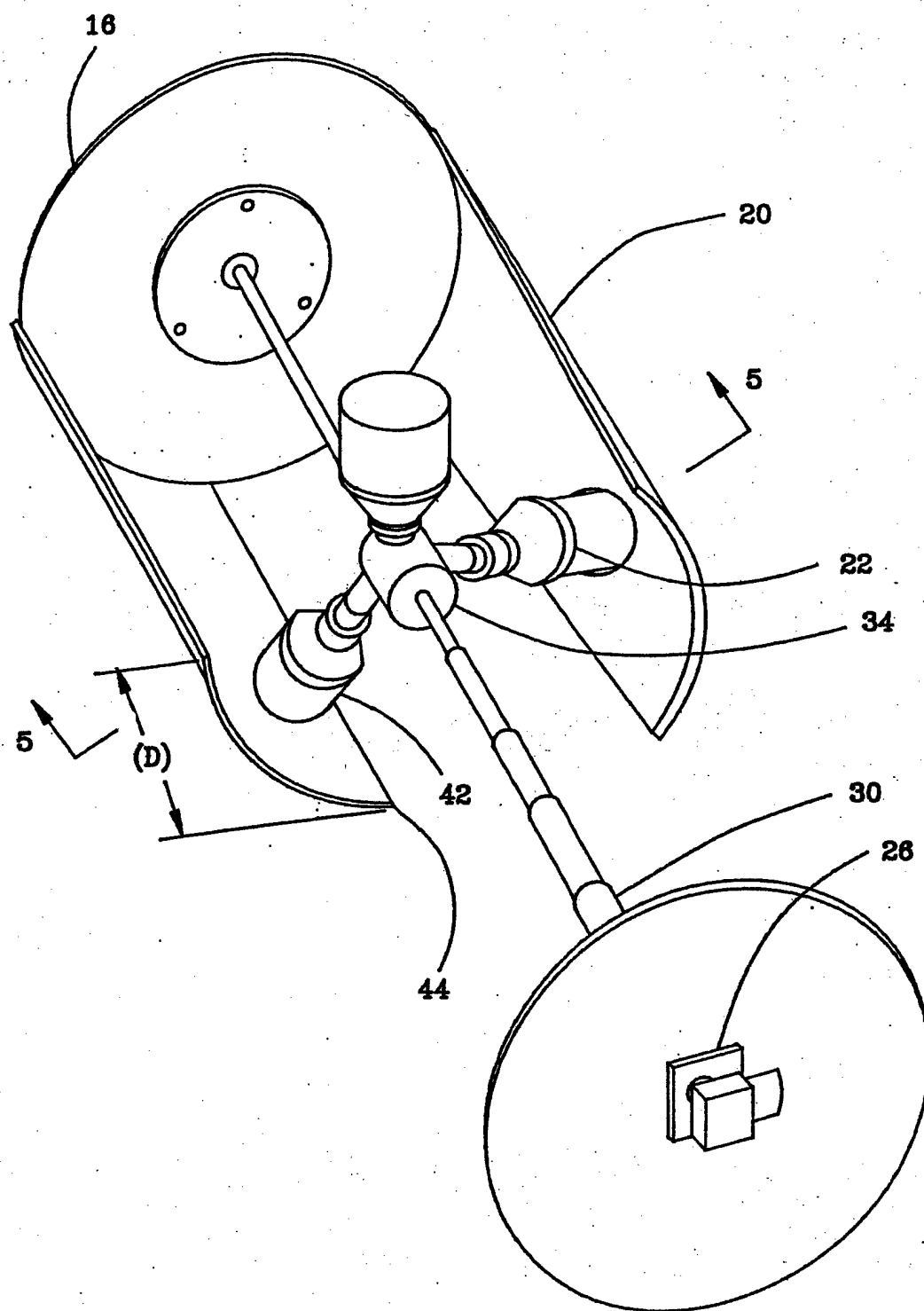


FIG. 4

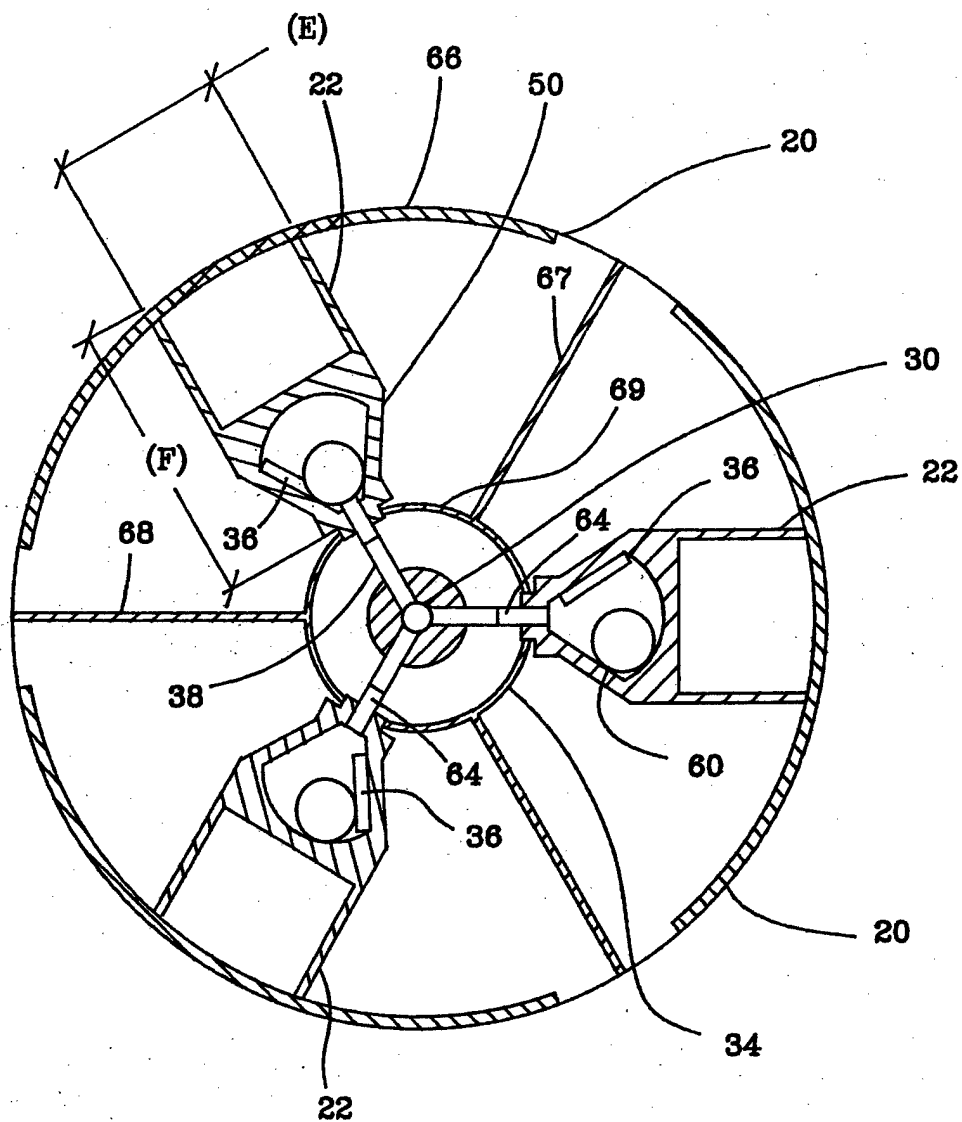


FIG. 5

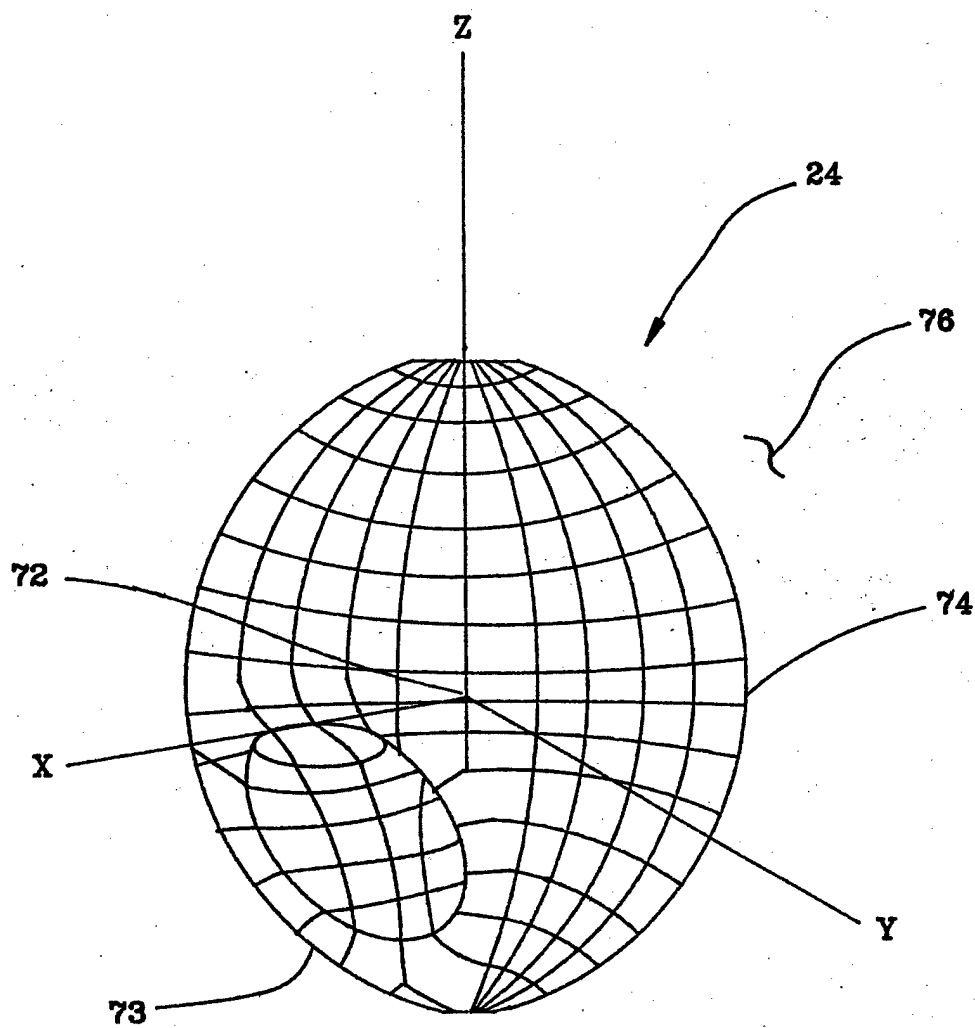


FIG. 6

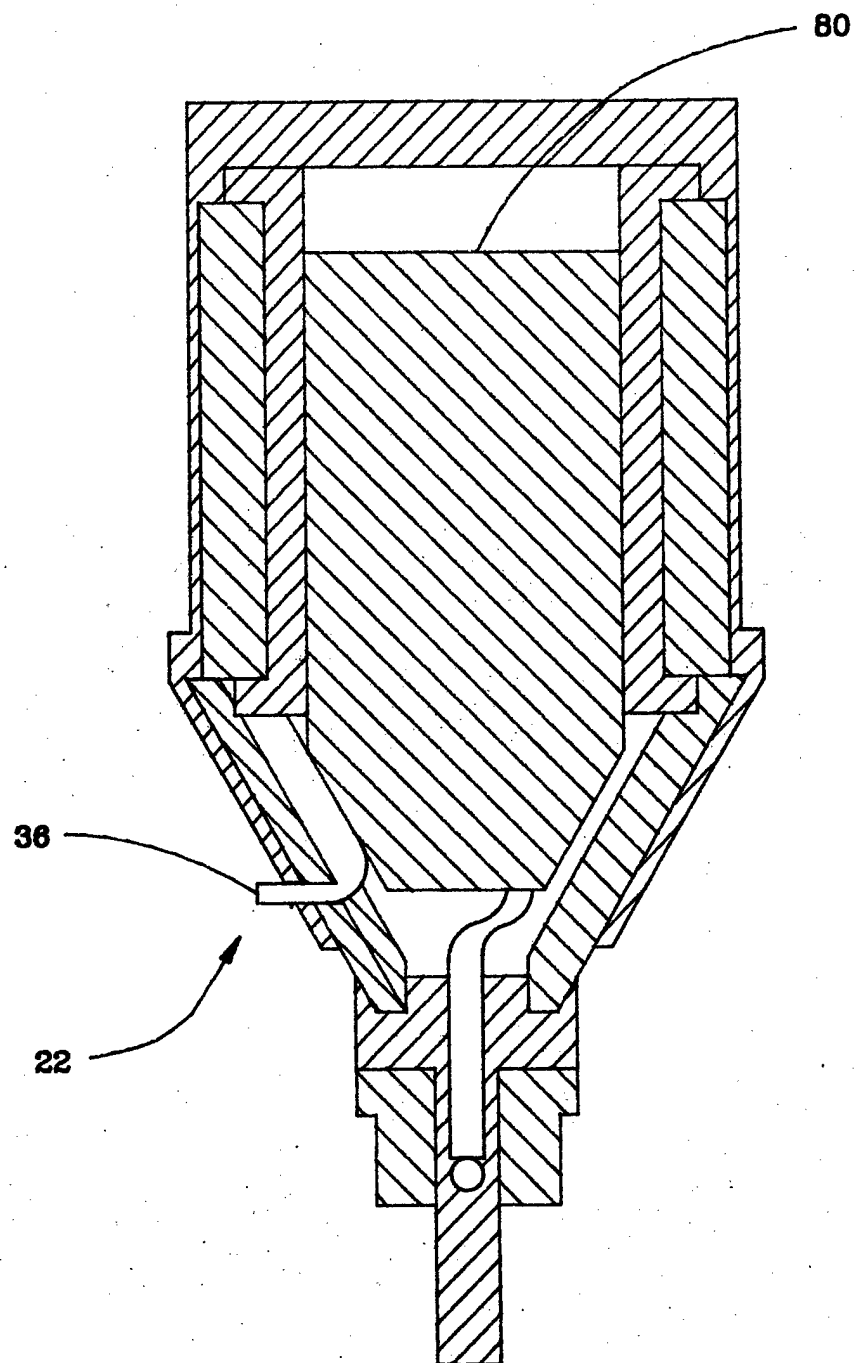


FIG. 7

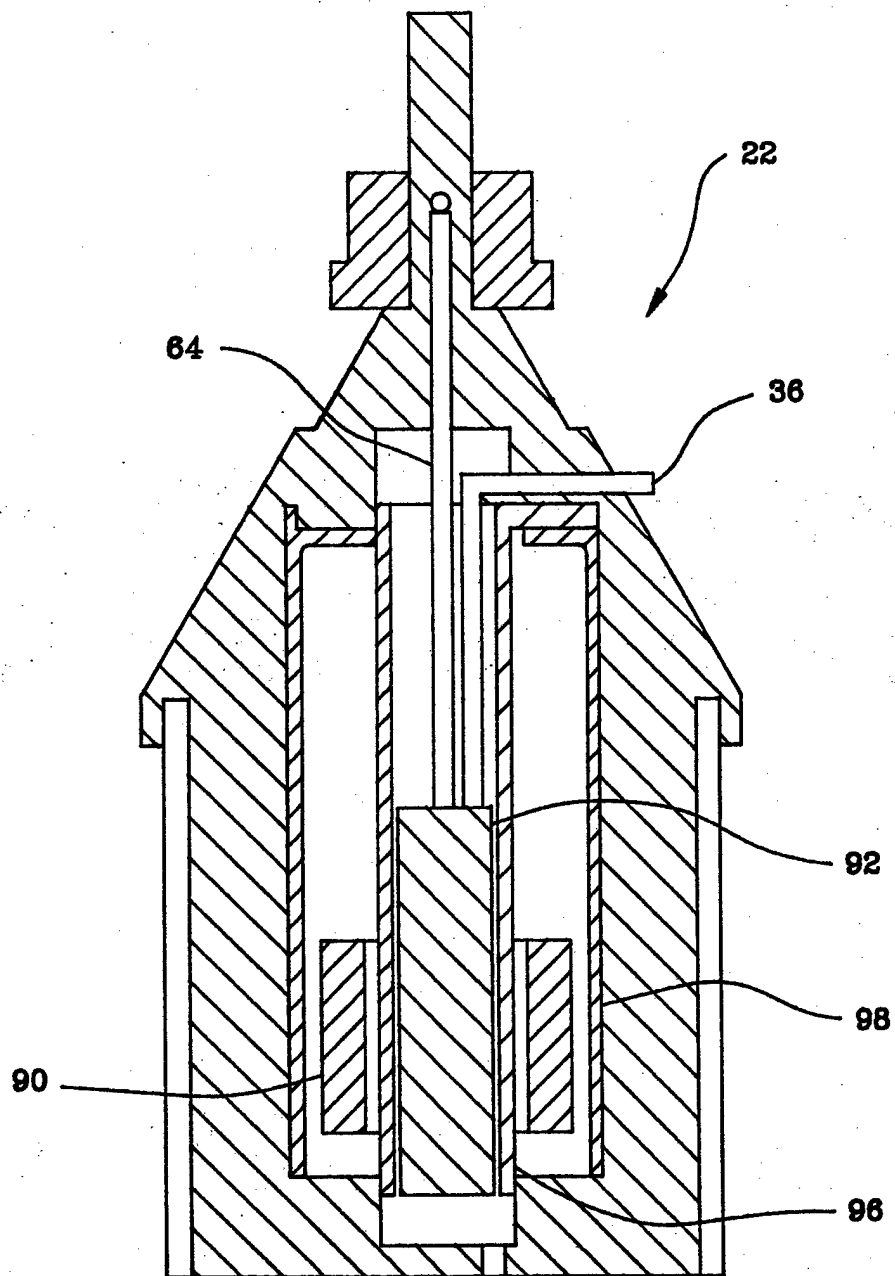


FIG. 8